NASA-CR-201072

Progress Report

Contract NASW-4803 **Dynamics of Superfluid Helium in Low Gravity**

Principal Investigator	David J. Frank
Contract period of performance	January 1996-June 1996
Report date	June 1996

Contract objective

The objective of this contract is to perform low-gravity verification tests of computational fluid dynamics (CFD) codes of which one that incorporates the two-fluid model of superfluid helium (SFHe). An existing CFD code had been modified to incorporate the unique physics of HeII (ref. 1). This required the addition to independently calculate the velocity fields of both the normal and superfluid components of HeII, calculate the differential velocity between the two fluids, the geometry-dependent critical velocity, and calculate the mutual friction between the two fluids when the differential velocity exceeds the critical velocity. This two-fluid model SFHe3D was developed at Lockheed Martin by Dr. G. Ross. The base code used for this model is FLOW3D by FLOWSCIENCE in Los Alamos, NM and is referred to as the single-fluid model.

Verification tests were accomplished by performing tests in the laboratory and flying a SFHe dewar on the NASA Lewis reduced gravity DC-9 aircraft while recording the slosh motion of the SFHe using a video camera. The acceleration environment is recorded for use as an input to the CFD code. The observed motion is compared to the motion predicted by the CFD code. Verification of the accuracy of the codes will aid in the design of satellites carrying SFHe such as the Space Infrared Telescope Facility (SIRTF), the Relativity Mission (GP-B), the Low Temperature Microgravity Physics Facility (Space Station), and other planned orbital helium systems such as the Satellite Test of the Equivalence Principle (STEP).

Progress

During this last performance period, considerable progress had been made. The dewar which was shipped to the NASA Jet Propulsion Laboratory (JPL) at the end of October 1995 was integrated into the JPL "Low Temperature Flight Facility". Full up systems test were performed at JPL prior to shipment of the dewar, the JPL Facility, and the ground support equipment to NASA Lewis. Flights on the aircraft were performed the week of January 29th.

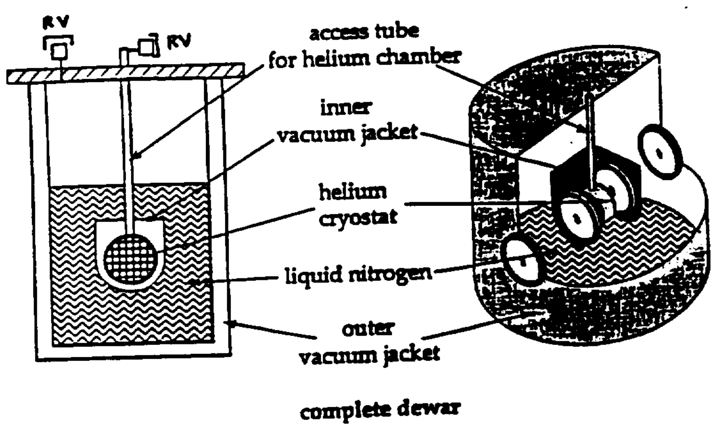
At this time, the data from the flights is being reduced and the CFD codes are being run to simulate the conditions during the flights.

Test Apparatus

The major parts of the test equipment consists of the SFHe Test Cell and the Flight Facility (Ref. 2). The Test Cell is a 0.2 liter thin disk (8.89 cm dia., 3.18 cm thick)which restrains the fluid motion to 2 dimensions. A more detailed description of the Test Cell can be found in the last progress report. The JPL Facility consists of a Float Package with a Dewar into which the Test Cell is installed and a data acquisition system. A video camera focuses on the SFHe in the Dewar. The Float Package is designed to free-float in the aircraft cabin. The data acquisition system is mounted in an electronic rack that does not float. The Float Package frame and the electronic rack are only connected by electrical cables which transmits the video image and outputs of the accelerometers and thermometers.

A schematic of the Dewar and Float package is shown in figure 1. The Test Cell is inserted into a small vacuum jacket which is then submersed in a liquid nitrogen bath. The outer vacuum jacket has windows on each side in line with the windows of the inner vacuum jacket and the Test Cell. Affixed to the Dewar is a video camera which views the helium through a mirror and the windows.

It is noted that the dewar is initially filled with normal boiling point (NBP) liquid helium at one atmosphere and subsequently pumped down to superfluid helium condition. During this pump-down 50 percent of the helium is evaporated which results in a tank half full when the test is started. Designing the dewar for subatmospheric top-off is considerably more complex and beyond the scope of the project.



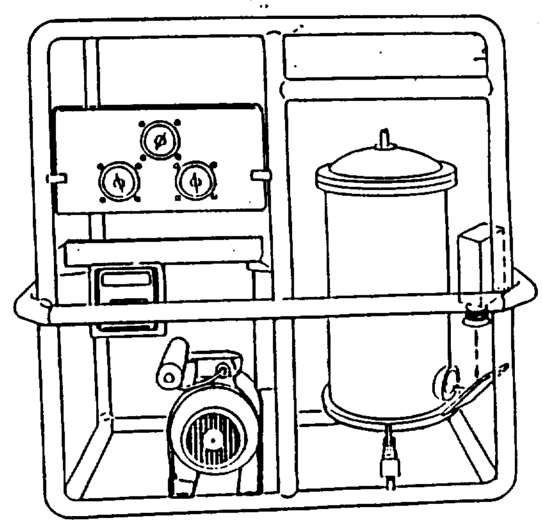


Figure 1: Schematic of Dewar and Float Package.

Tests

A number of slosh tests were carried out in one gravity in the laboratory to characterize fundamental frequency and damping. Results of these tests were reported in the last progress report and are not repeated here. The series of flights on the NASA Lewis reduced gravity DC-9 aircraft were performed to determine if correct fundamental frequencies can be predicted based on the acceleration field. Tests in zero gravity were performed to verify zero gravity motion.

This was the first time that the NASA Lewis DC-9 organization flew a cryogenic experiment. Due to the servicing aspects of cryogens and the limited hold time of the superfluid helium we requested some unique servicing windows prior to flight. The NASA/Lewis personnel were very cooperative.

High to low-g behavior

Three methods of predicting fundamental frequency were used. The single and two-fluid models and a closed form relationship developed by McCarty and Stephens (ref. 4). Figure 2 shows a typical 0.02g simulation of the two-fluid model where the velocity of each the normal and superfluid component is displayed. Tracking the center of mass of the total fluid allows determination of the fundamental frequency. Figure 3 shows results of the models for a Test Cell approximately half full at 1.7K. It can be seen that there are no significant differences between models.

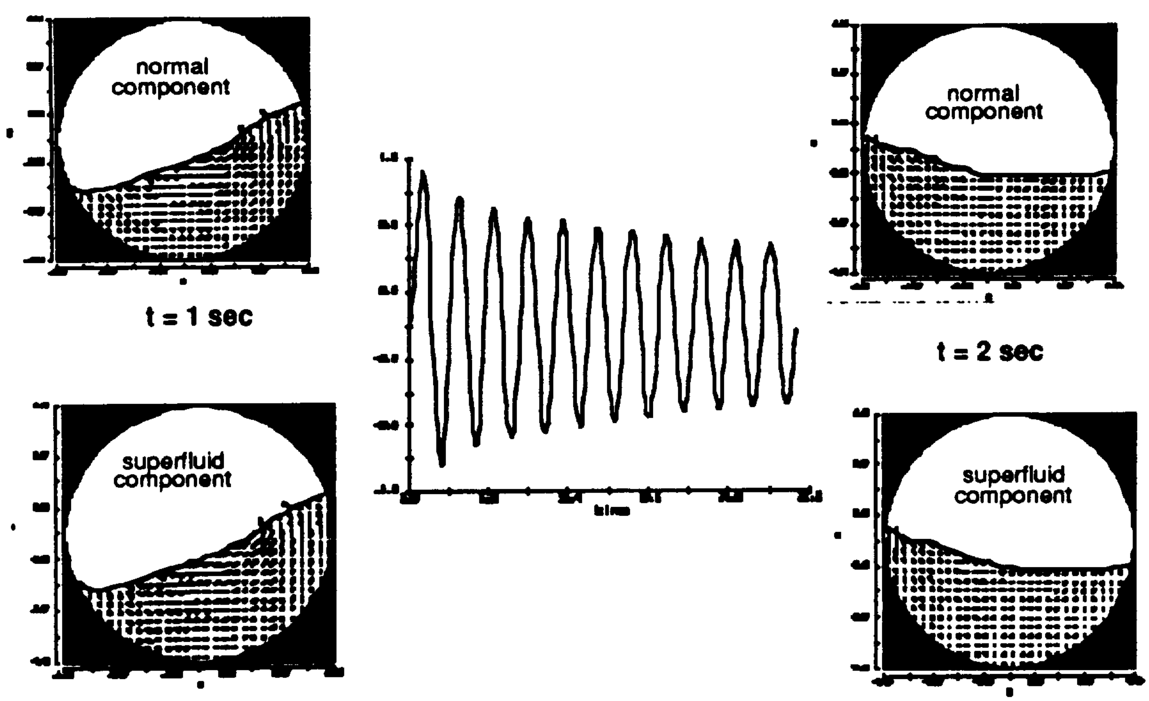


Figure 2: Two-fluid model simulation. Simulation shows fluid field of both the normal and superfluid components and time history of the center of mass.

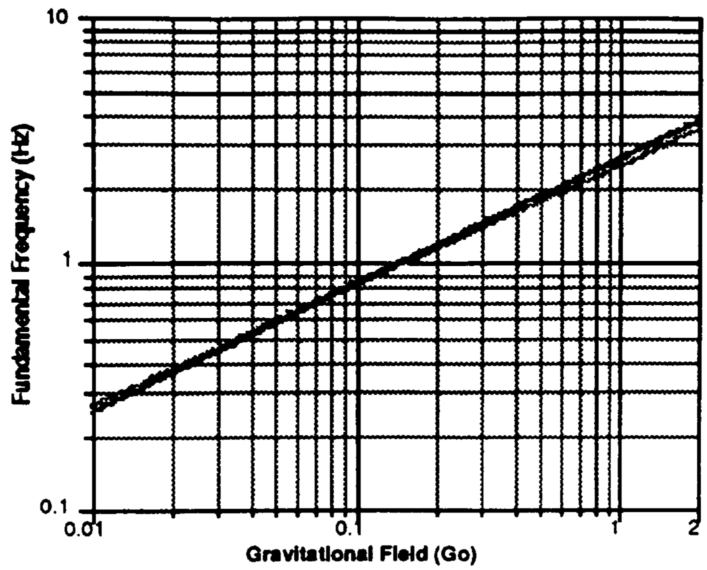


Figure 3: Three methods of predicting fundamental frequency. Predictions show no significant differences.

Tests at 1-g were performed in the laboratory while tests at high and low gravity were performed on the NASA DC-9 aircraft. During the tests, the Float Package was kept secured to the floor and the trajectory of the aircraft was adjusted to get accelerations as low as 0.04g. Figure 4 shows a typical acceleration profile during this test which shows a low gravity period of 15-20 seconds. The high-gravity data was recorded prior to and after the aircraft descent during the parabolic maneuver. Figure 5 shows a picture of the fluid during the 0.04g acceleration. It can be seen that the liquid-vapor interface is still fairly dominated by the acceleration field. The Bond number based on the radius of the Cell is 334.6. Figure 6 shows the test data along with the predictions over the 12-50% fill level range tested. It can be seen that the fundamental frequency of the superfluid helium behaves under the condition where gravity still dominates and can be modeled as a single Newtonian fluid.

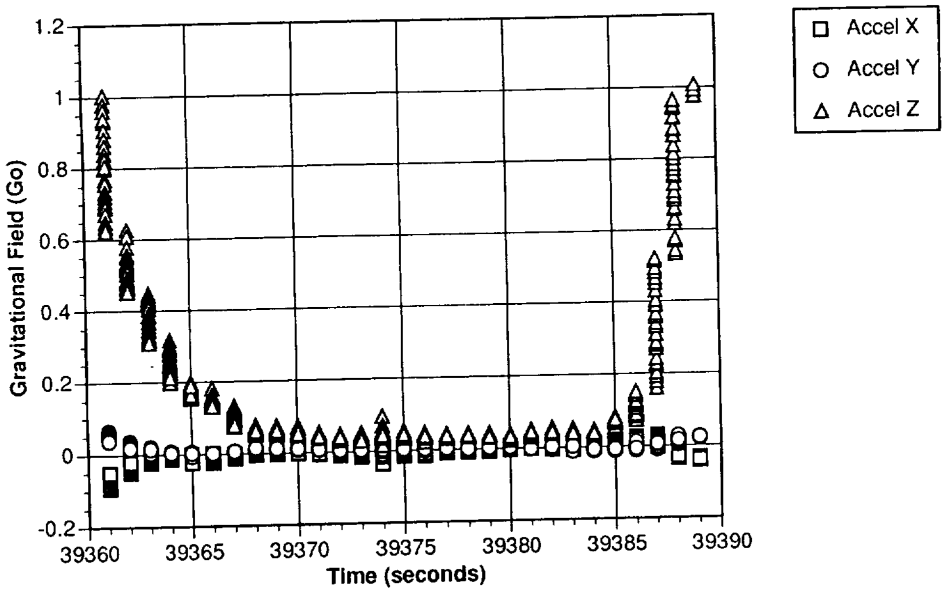


Figure 4: Typical DC-9 gravitational field profile. Periods of 15-20 seconds of low gravity were achieved during this 0.04g parabola.

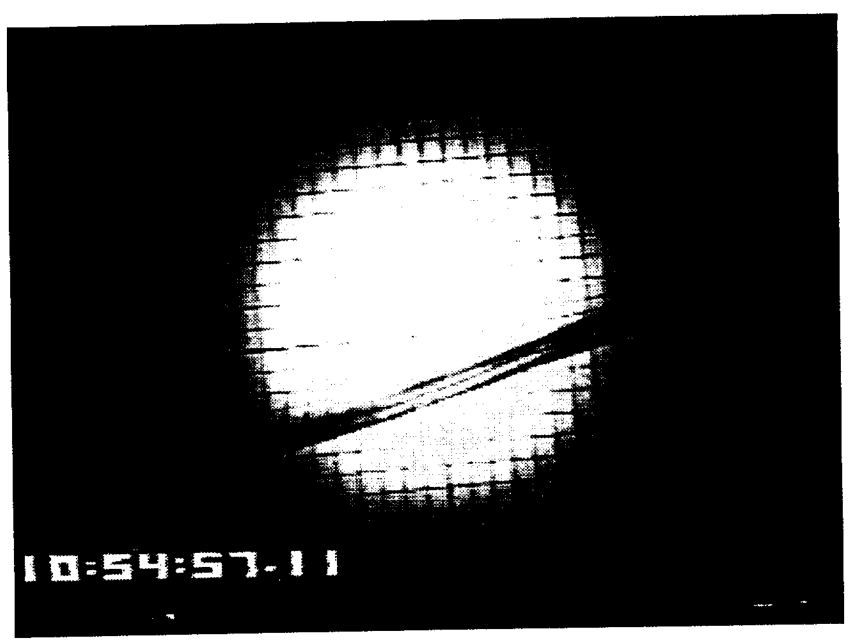


Figure 5: Superfluid helium in low gravity. The liquid-vapor interface is still dominated by the 0.04g acceleration field.

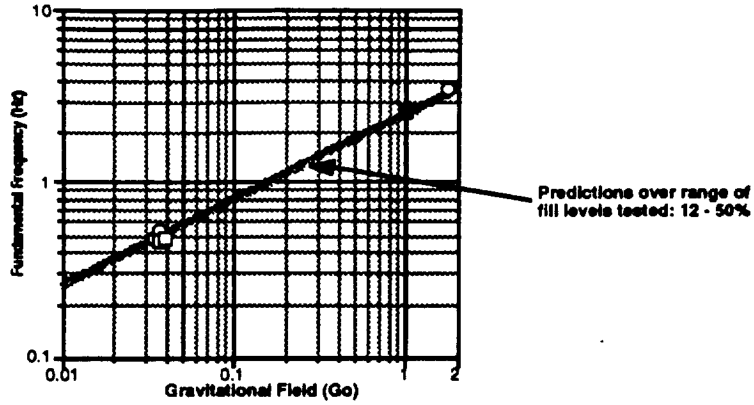


Figure 6: High to Low-g Test Results. Results indicate that fundamental frequency of superfluid helium behaves and can be modeled as a single Newtonian fluid.

Zero-g behavior

In zero gravity, the liquid-vapor interface profile is dominate by surface tension. The fluid takes on a profile to achieve it's lowest energy state which has a single vapor ullage. In a large tank this ullage will be spherical. In the case of this 2D Test Cell the ullage is nearly in the form of a disc. Figure 7 shows a prediction of the movement of the fluid in 0-g after being subjected to a lateral disturbance of 1 mili-g for 1 second. Figure 8 shows the plots of the center of mass of the fluid predicted by the single and two-fluid models. It can be seen that in zero-g, the two models predict different damping of the fluid with the two-fluid prediction showing a higher damping rate.

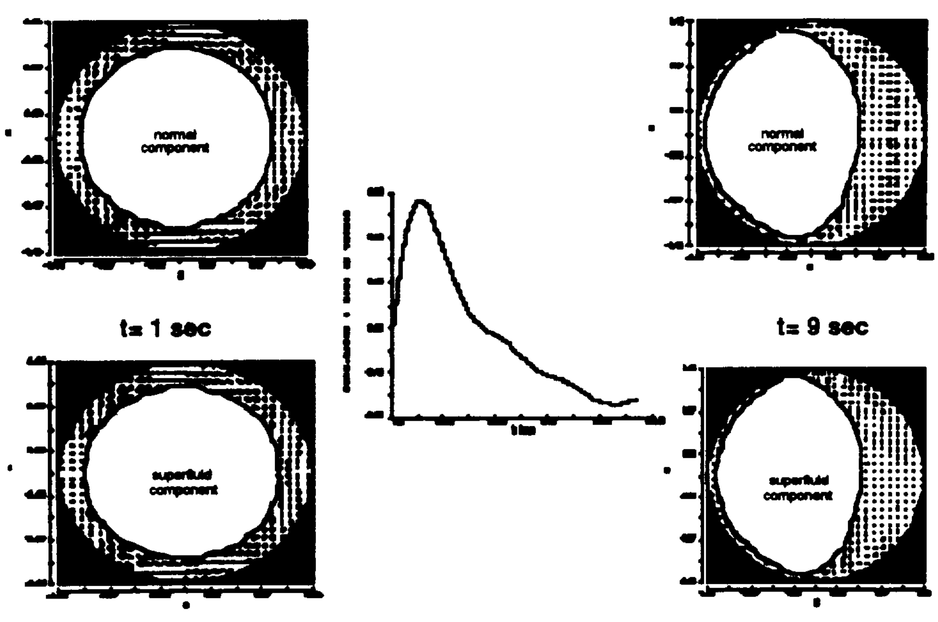


Figure 7: Predicted two-fluid zero-gravity fluid movement. Figure shows movement of the fluid after being subjected to a lateral disturbance of 1 mili-g for 1 second.

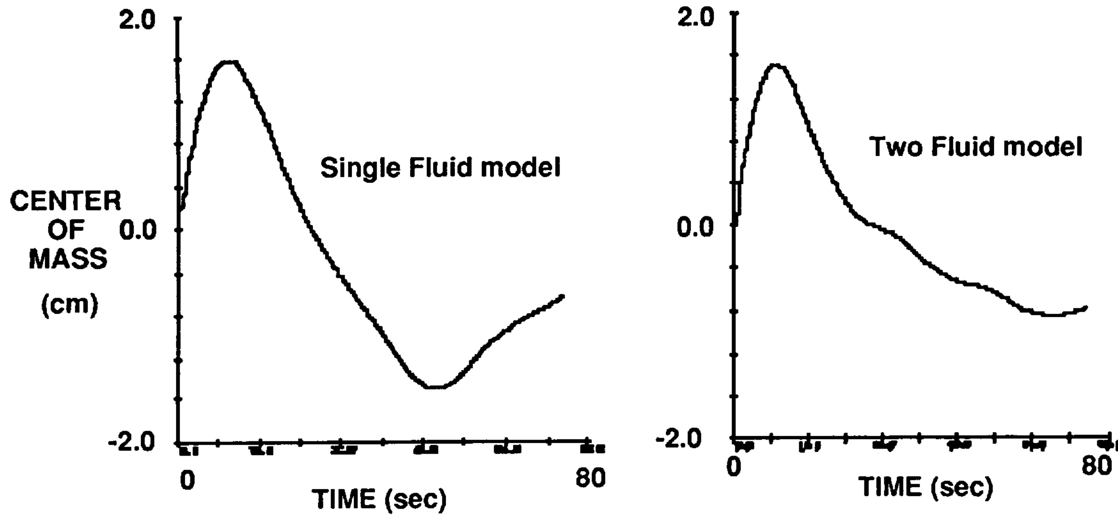


Figure 8: Center of mass of the fluid predicted by the single and two-fluid models in zero-g. The two models predict different damping of the fluid with the two-fluid prediction showing a higher damping rate.

A series of test were performed at zero-gravity. In these tests the experimental Float Package was allowed to free-float in the aircraft as shown in figure 9. After entering the zero gravity trajectory, the fluid would transition from a high-g profile to the zero-gravity disc profile as shown in figure 10. The fluid was then disturbed and the resultant motion recorded.

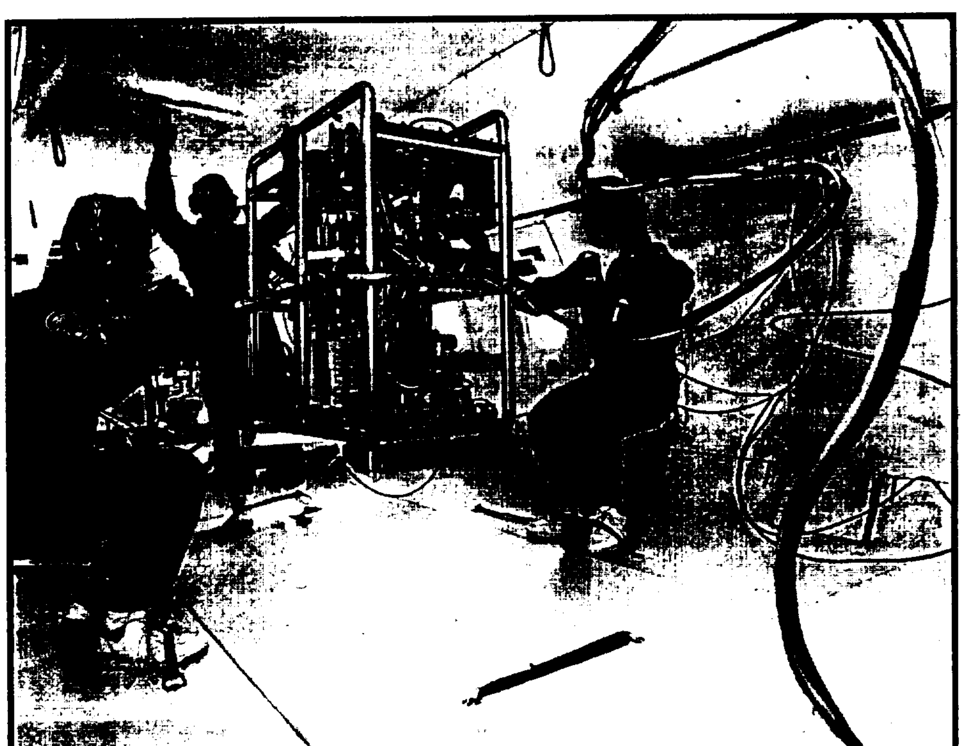


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Figure 9: Free-floating of the experimental Float Package.

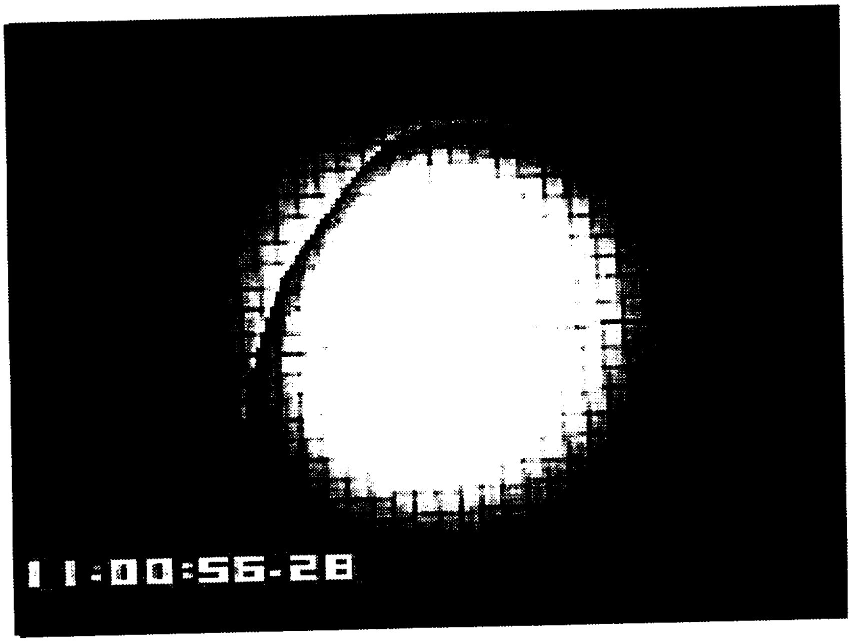

Figure 10: Zero-gravity profile of the fluid.

The aircraft flights were performed during the early part of this year and at the time of writing of this paper, the evaluation of the zero-gravity data is still in progress. The first estimates is that the results confirm that the fundamental frequency is very low as predicted. The test duration may be too short for confirming actual zero gravity fundamental frequency predictions.

Summary

Results of tests show that modeling of SFHe in 1-g can be accomplished with both the single-fluid and two-fluid models which will accurately predict fundamental frequencies and damping of the fluid motion. Over a range of accelerations were surface tension forces are not dominant, both single and two-fluid models predict fundamental frequencies. Of main interest to designers of spacecraft attitude control systems are frequencies in zero-g. The data recorded during zero-g is still being evaluated.

Preliminary analysis is showing that durations in aircraft testing are too short to get conclusive data. In order to increase the frequency, a smaller test cell could be used. The possibility of repeating the tests with a smaller cell is being evaluated.

Remainder plan

The following plan will complete this project. The flight data that still has not been reduced will be analyzed and the CFD codes will be excerzide against them.

In addition some analysis is being conducted to determine if a much smaller test cell could be used to increase the zero-g frequency such that more meaningful data could be acquired in the short 15-20 seconds available in the aircraft. If a smaller cell would allow to get data, then a fairly major hardware redesign, which would incorporate a cell with a double guard, would be required. The Test Cell would have to be guarded by superfluid helium which in term would have to be guarded by liquid nitrogen.

It is possible that the resources still available to this contract could cover the expanse of redesigning and building a new dewar. Cost occurred to date have been lower then originally anticipated due to the availability of the JPL Facility. The benefit from the JPL Facility more then offset the extra cost of the computer resources. As explained in previous progress reports, computer charges went from being an overhead item to a direct charge to the contract.

REFERENCES

1. Ross G., Dynamics of Superfluid Helium in Low Gravity, Doctor of Philosophy Dissertation, Stanford University, July 1994.

2. Mason P., B. Chave, and T. Brunzie, A Low Temperature Flight Facility for Zero Gravity Aircraft. Presented at this workshop, 1996.

3. Ross G., Behavior of Helium II in Low Gravity, Proceedings of the NASA/JPL 1994 Microgravity Low Temperature Physics Workshop, JPL D-11775, pg. 156, May 1994.

4. McCarty, J.L. and D.G. Stephens, Investigation of the natural frequency of fluids in spherical and cylindrical tanks, NASA Technical Note D-252, 1960.